Hybrid Particle Simulation of High Altitude Nuclear Explosions in 3-D Using HPC

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Introduction

- Review the history of HANE effects.
- Discuss physical issues associated with Any HANE simulations.
- Discuss the Hybrid Particle Code, SHYPS.
- Discuss importance of HPC to this effort.
- Discuss our HPC requirements.
- Conclusions and comments.

High Altitude Nuclear Effects

- High Altitude tests by U.S. and USSR showed many surprising results.
- Starfish 1962 - 400 km altitude was our last test.
- These tests showed that radiation from fissile material could become trapped on the Earth's magnetic field lines
- A variety of satellites were damaged by this trapped radiation.
- To this day the dynamics of the debris motion is not understood.

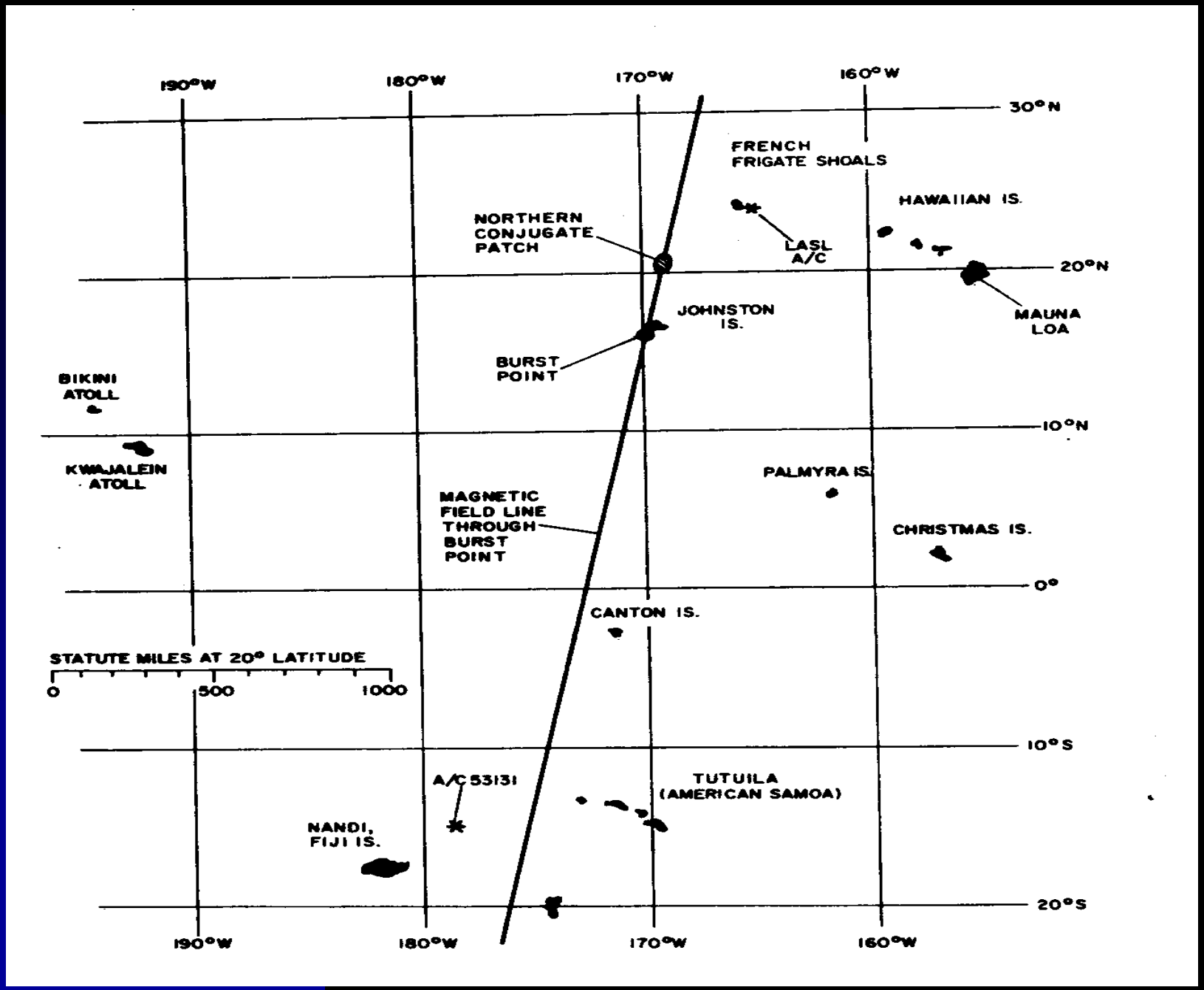
190°W
180°W
170°W
160°W
30°N
20°N
10°N
0°
10°S
20°S
FRENCH FRIGATE SHOALS
HAWAIIAN IS.
NORTHERN CONJUGATE PATCH
LASL A/C
MAUNA LOA
JOHNSTON IS.
BURST POINT
BIKINI ATOLL
KWAJALEIN ATOLL
PALMYRA IS.
MAGNETIC FIELD LINE THROUGH BURST POINT
CHRISTMAS IS.
CANTON IS.
STATUTE MILES AT 20° LATITUDE
0
500
1000
A/C 53131
TUTUILA (AMERICAN SAMOA)
NANDI, FIJI IS.

Fig. 3.
Teak Event seen from top of Mount Haleakala (Maui) at approximately H + 1 minute.

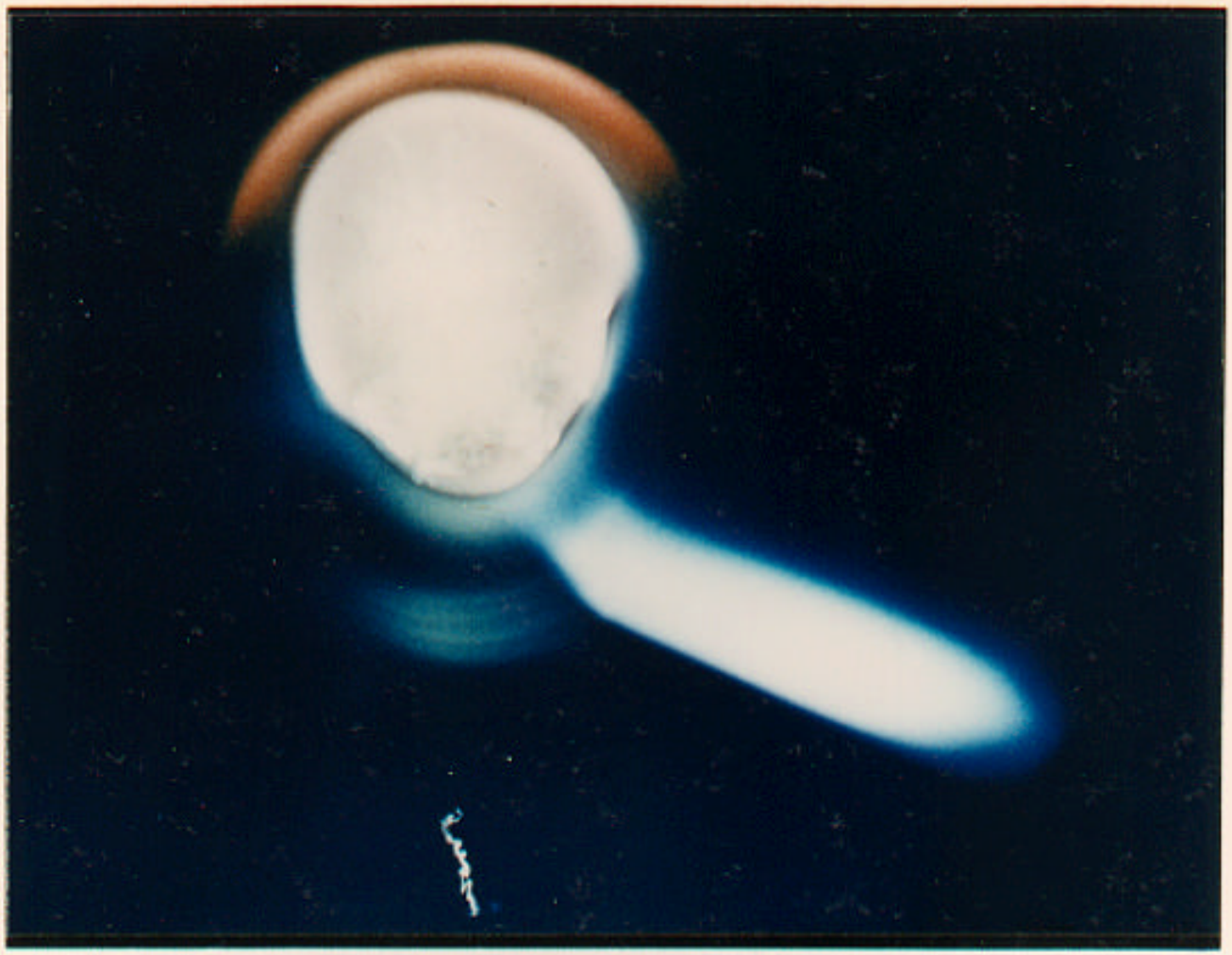

Fig. 4.
Kingfish Event seen from high-flying aircraft.

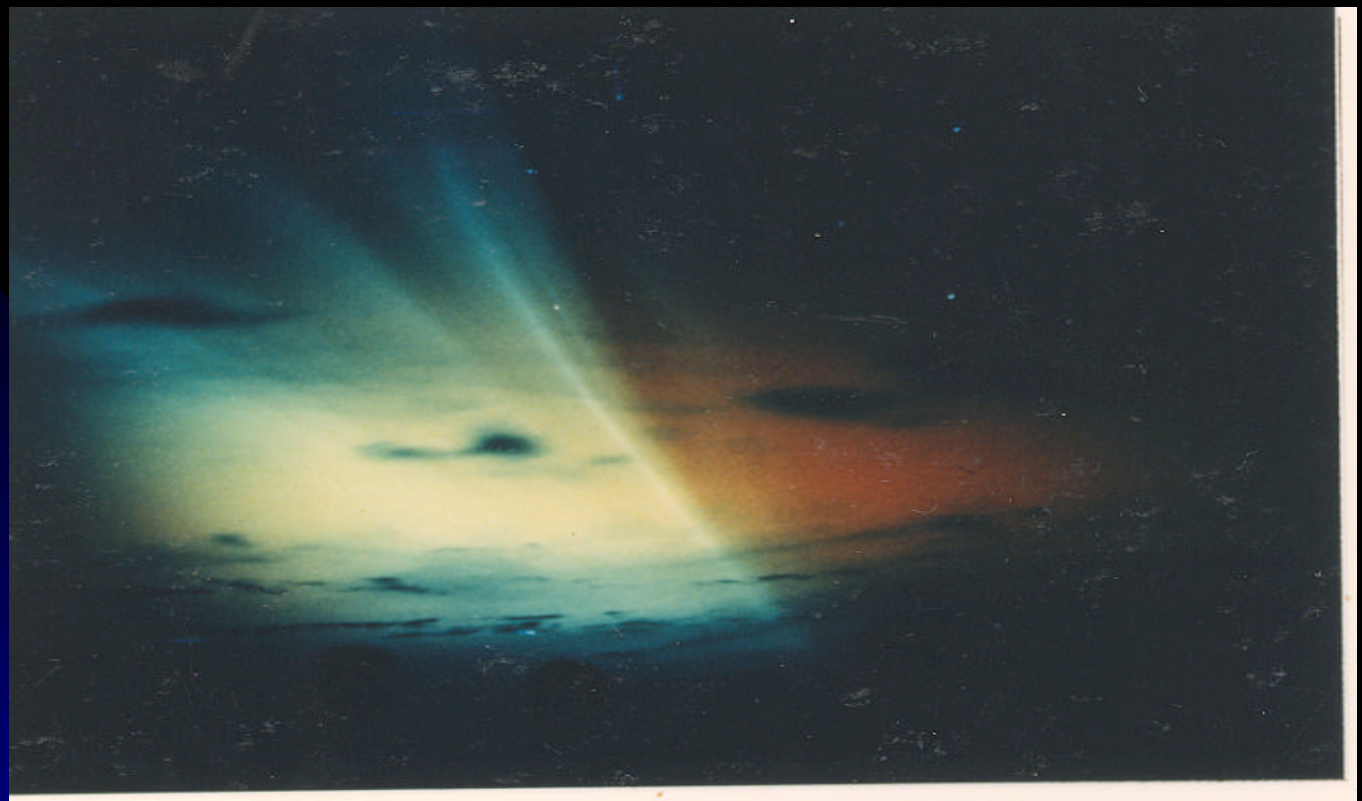

Fig. 7a.
Starfish Event seen from Christmas Island. Air fluorescence excited by debris motion at approximately H + 1 minute.

Current Issues to be addressed

- The parameter space that are being explored is not appropriate for codes making the fluid assumption.
- New data suggests that Nuclear weapons energize radiation belts with more than one mechanism
- The problem is 3-D by nature.

Parameter Space of Interest

- The interactions are completely electromagnetic.
- The usual fluid dynamic assumptions are not valid
- Multiple ion species dynamics is required.

Super-Alfven Shock Physics at High Altitude

- Collisionless shocks are very different from hydrodynamic shocks
  - Hydro shocks are formed on molecular scales
  - Collisionless shocks are formed on ion gyroradii scales.
- Hydro shock thicknesses are subscale phenomenon (mm to cm)
- Collisionless shock thicknesses are on scales larger than the fireball (10 km to 100km)

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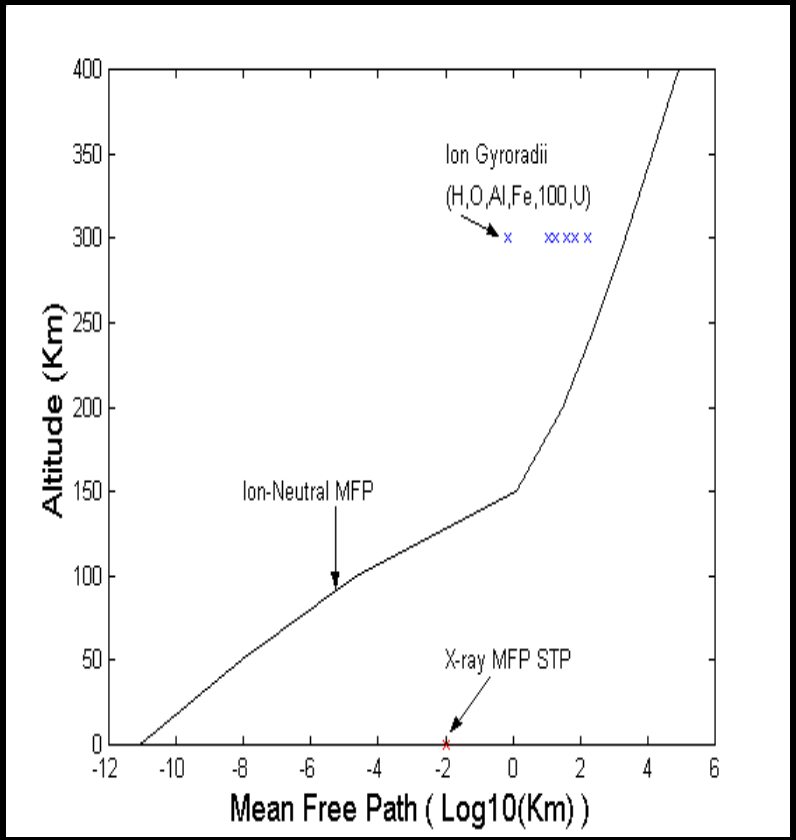
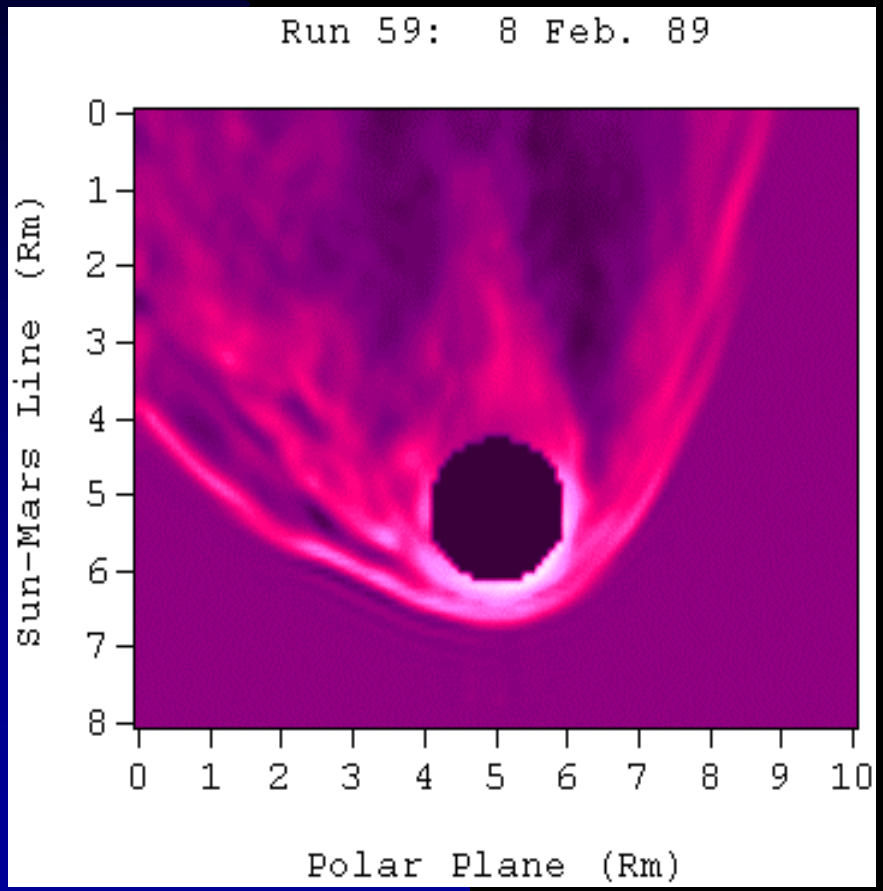
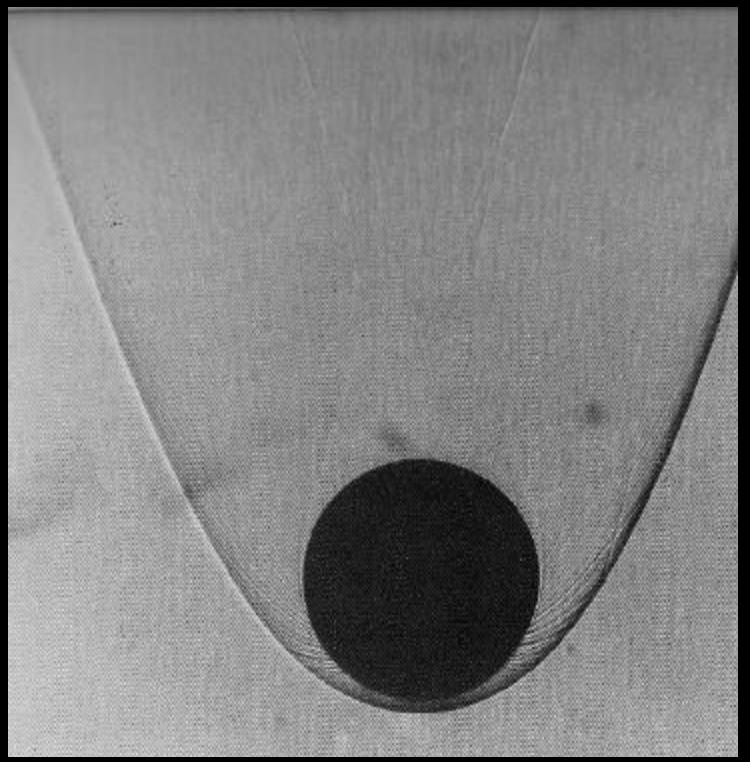


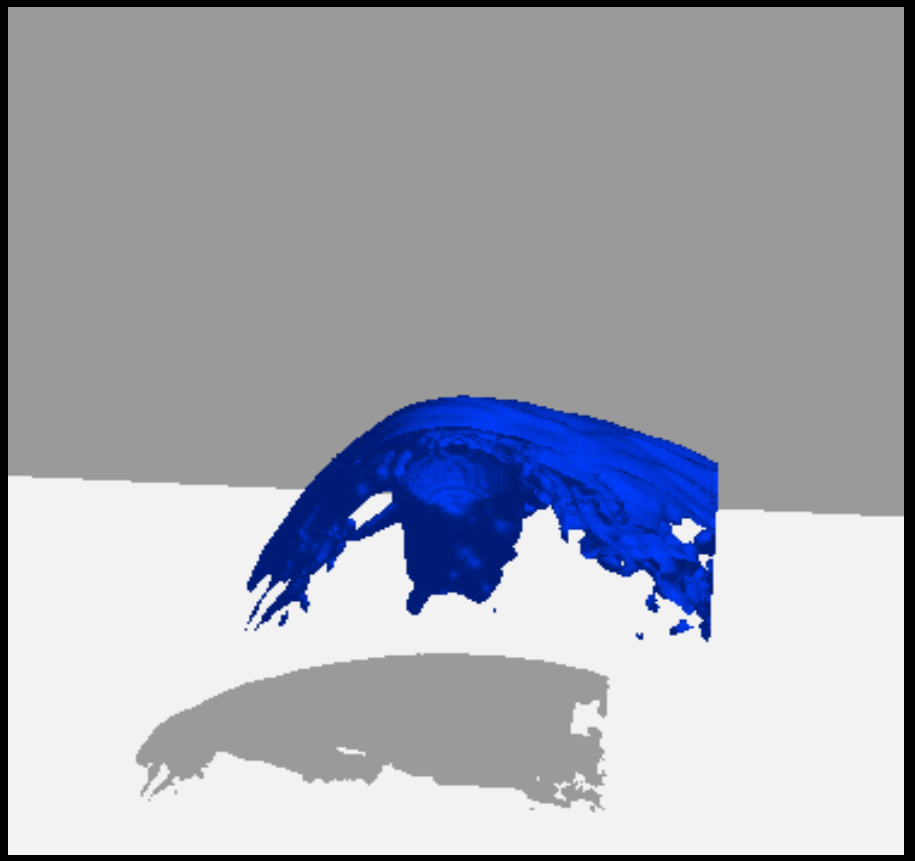
Comparison between Hydro and Kinetic Shocks





Full 3-D Kinetic Shock

- Mars Simulation using a version of SHYPS
- Note shock asymmetry.
- Asymmetry is a result of diamagnetic effects.
- Predicted and was confirmed by Mars Global Surveyor.



Belt Pumping Physics Occurs inside the Shock

- Debris dispersal is controlled by the collisionless shock and the state of each of the debris species:
  - Charge state (single or multiple)
  - Velocity
  - AMU (atomic mass unit)
- Acceleration of ambient relativistic electrons is controlled by kinetic effects and waves within the shock

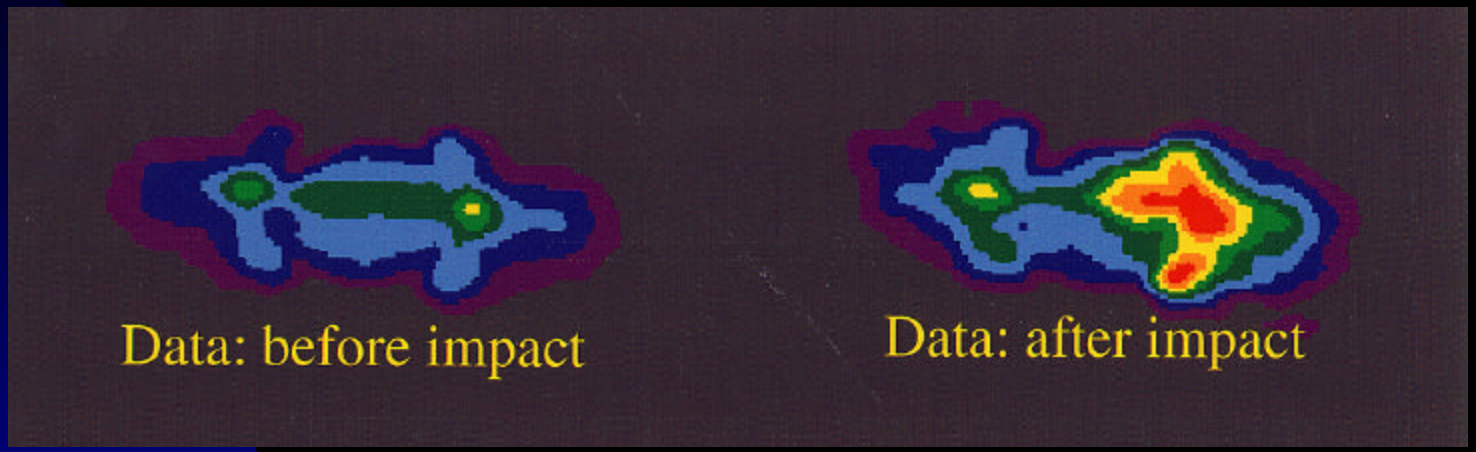
Simulations Must Include Shock Physics

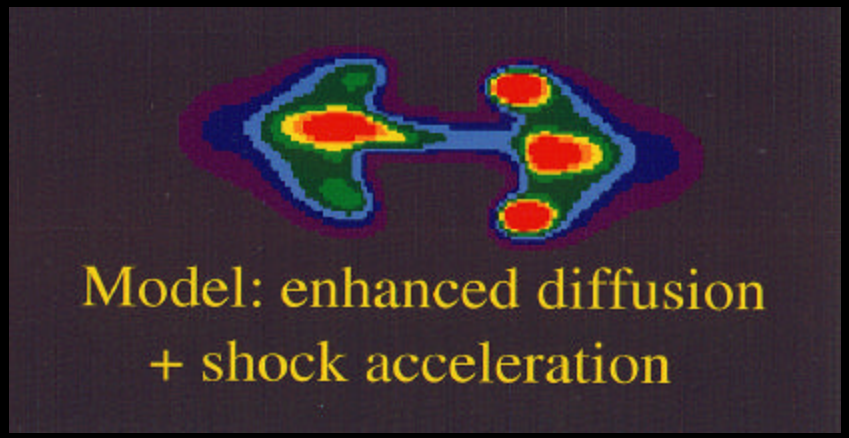
- Hydro/MHD codes assume shock physics to be subscale.
- Shock capturing schemes use anomalous viscosity or Godonov scheme, but assume shock forms.
- Physics of shocks requires a discrete,particle-kinetic treatment.

Belt Pumping Mechanisms

- There are two ways High Altitude Nuclear Bursts pump the Earth's radiation belts
  - Dispersing fissile material onto high altitude magnetic field lines.
  - Shock acceleration of the ambient relativistic electron population.
- Both mechanisms require real time modeling of Super-Alfven shock.

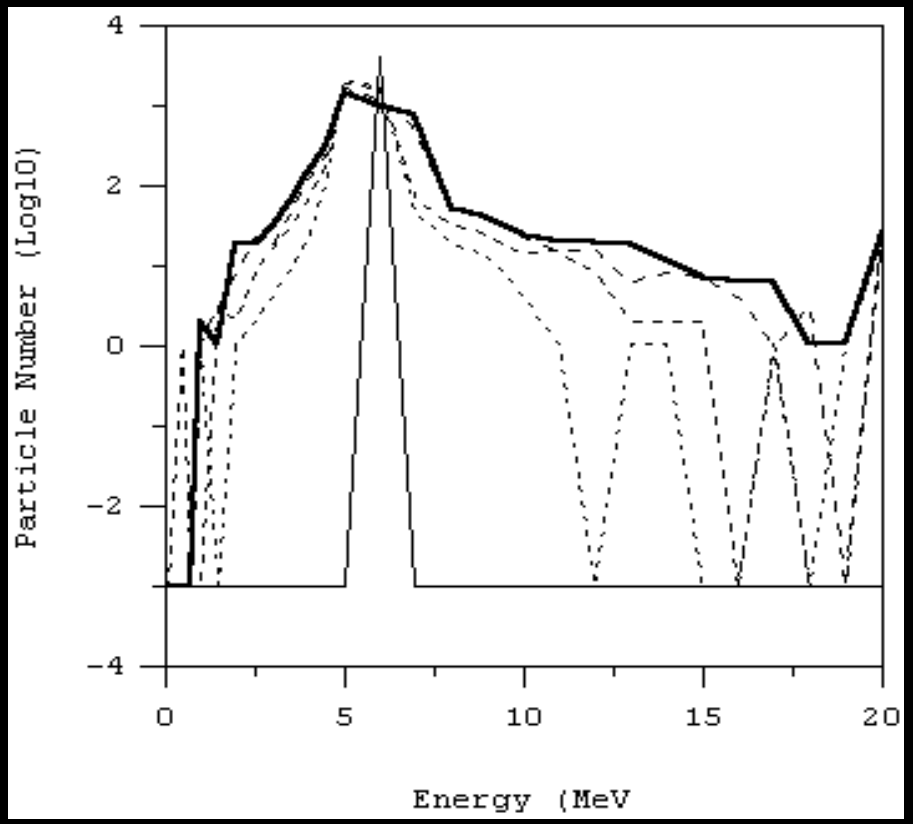
Modeling of Shock Acceleration





Shock Acceleration Of Relativistic Electrons

- Results of 6 MeV electrons in a HANE environment.
- Time evolution is fast, < 0.2 sec.
- Energization is strong, > 20 MeV



Hybrid Code - SHYPS

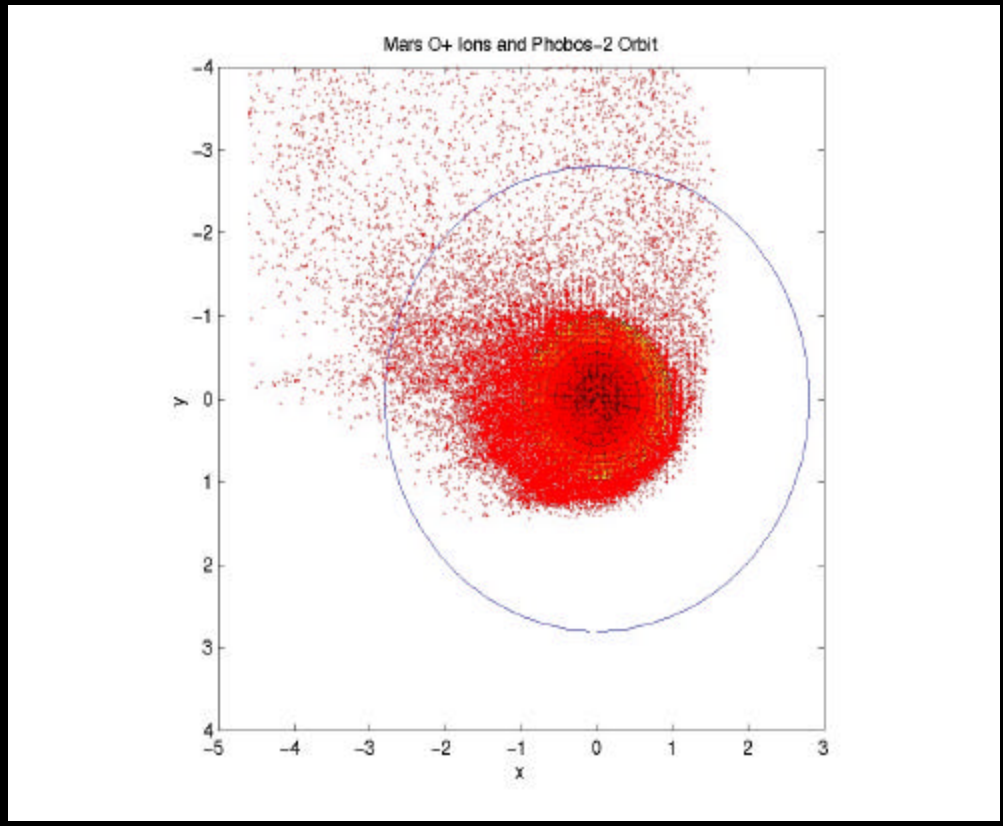
- The hybrid code is a kinetic-particle code.
  - The electrons are a neutralizing fluid.
  - The ions are individual particles integrated in time.
- The code does not include light waves.
- The code does include many electromagnetic waves and self-consistently calculates the particles locations and the electromagnetic fields.

Hybrid Code - Continued

- The algorithms in SHYPS have been tested out against large data sets.
  - Plasma experiments
  - Ionospheric processes
  - Space physics data from other planets.
- The results have been continuously successful in explaining and predicting the data collected.

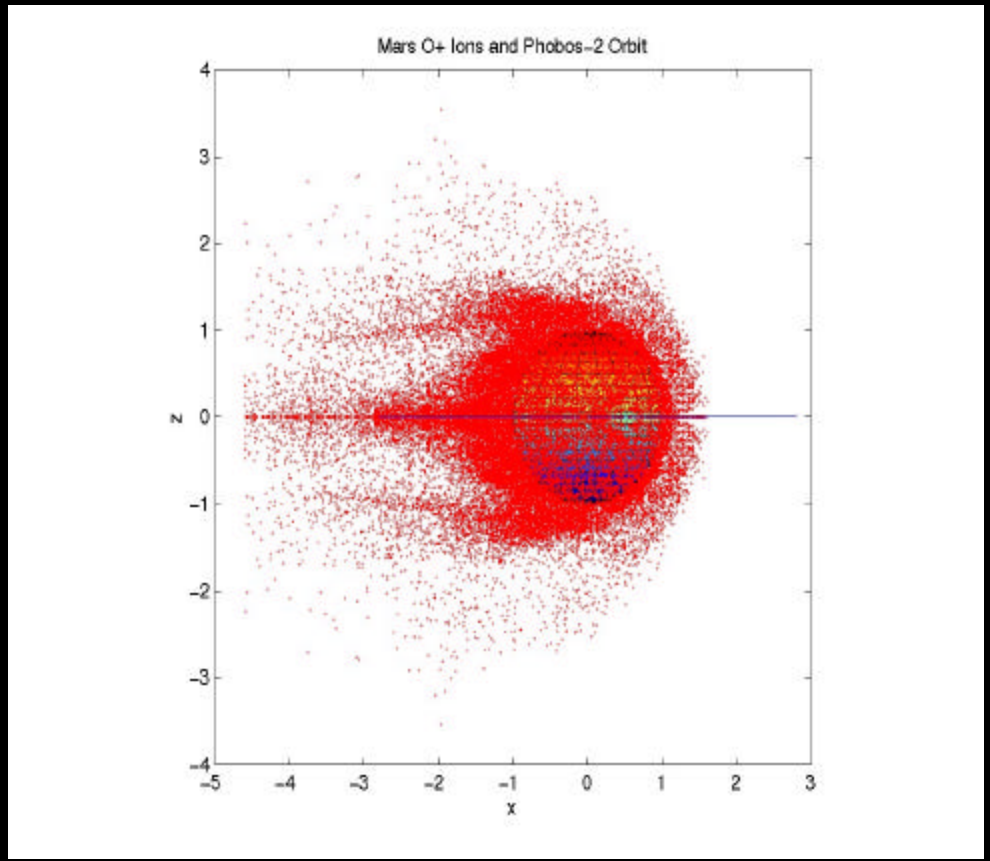
Examples of Validation-Kinetic Effects

- Mars Data vs. Simulations
- Comparing O+ ions with sensor data.



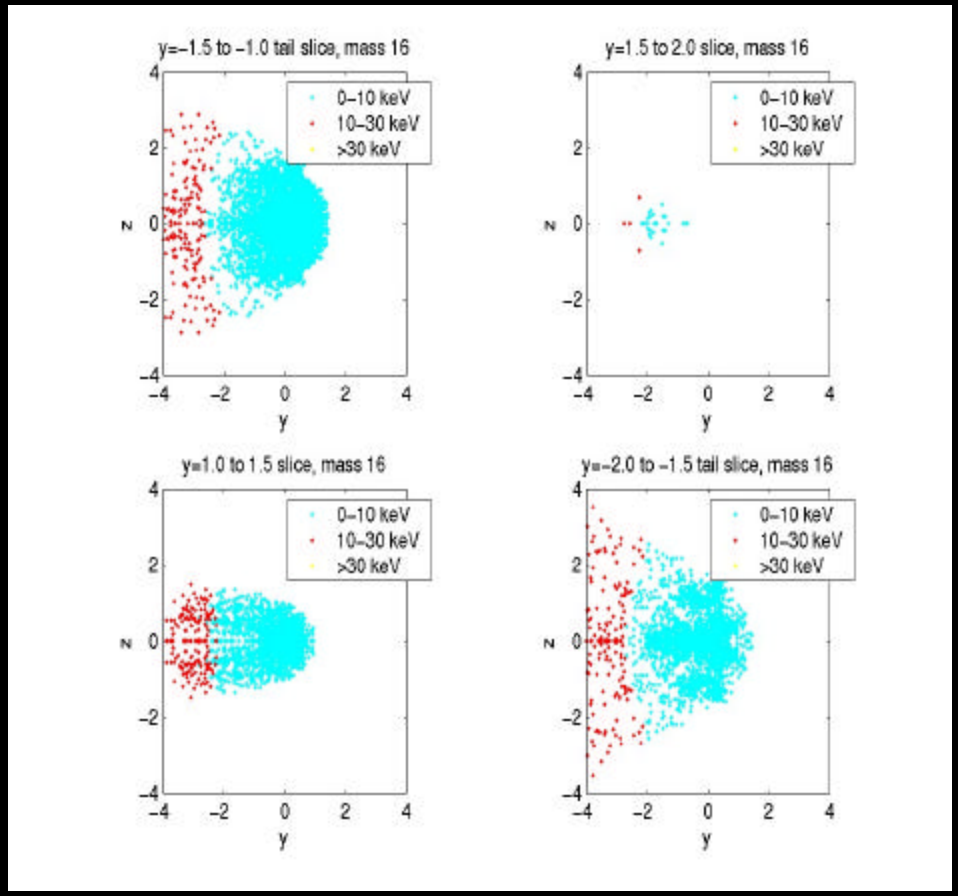
Examples of Validation

- Mar Simulation shows the asymmetry of ion pickup.
- Compares well with data.



Examples of Validation

- Energy Spectra from Mars Simulation.
- Comparison with spacecraft data is ongoing and is usually very good.



Impact of HPC

- For the first time the issue of trapped radiation can be correctly addressed.
- For the first time we can learn where and how the debris is dispersed/deposited following a nuclear weapon explosion.
- For the first time we can begin to assess the models that have been used for years to predict vulnerability of our space based assets.

Advantages of HPC

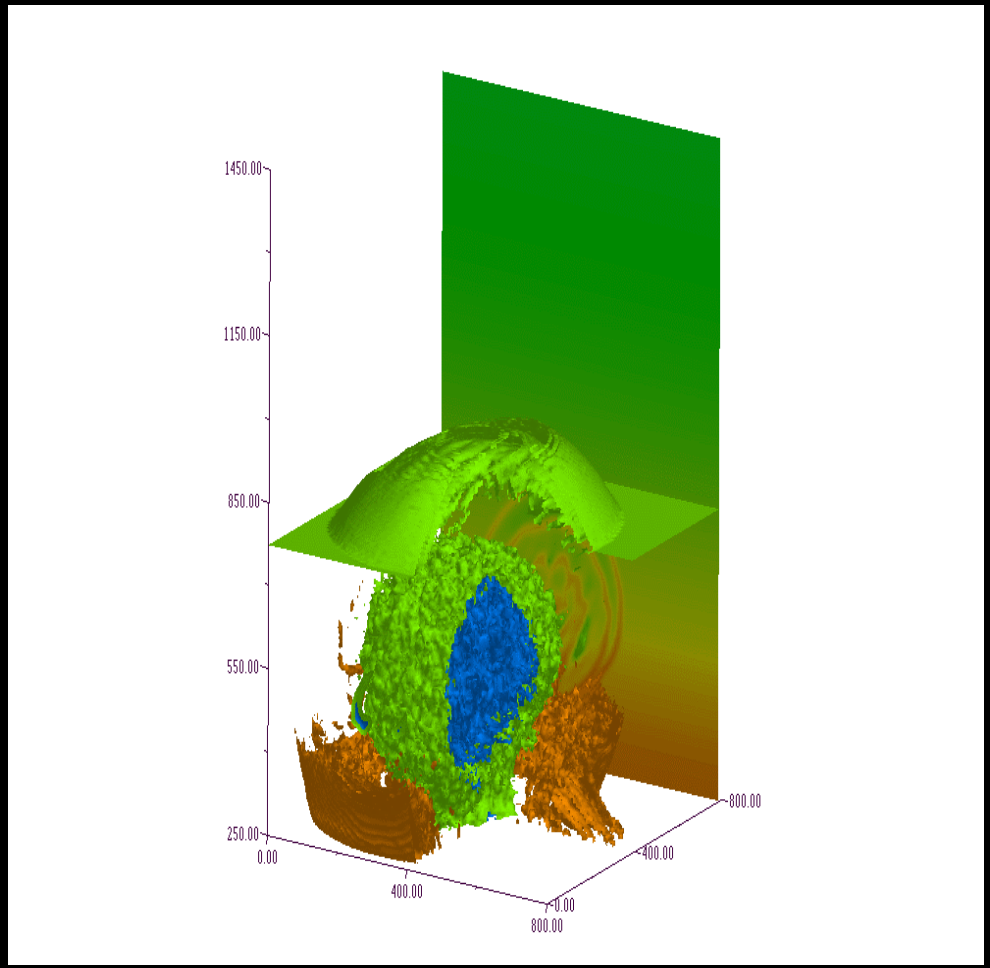
- We can go to fully 3-D simulations
- We can perform these simulations with many different ion species with many different charge states.
- We can load realistic velocity spectra and geometric features
- Finally realistic magnetic field geometries and atmospheres can be incorporated.

New Schemes for HPC Permit Kinetic Simulations

- HPC Challenge program has allowed fully 3-D kinetic simulations of HANE
- Debris dispersal on a species by species level can now be tracked and fully understood.
- Shock acceleration of relativistic electrons can now be simulated.

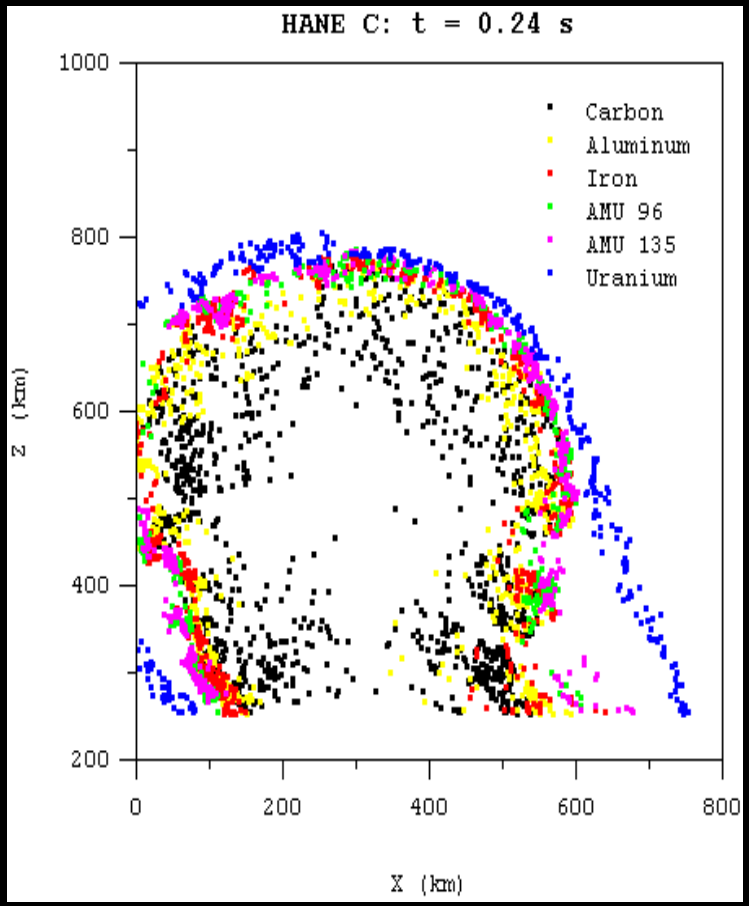
Example of a Starfish Calculation

- In this plot of ion density many of the features of interest are shown.
  - Filamented plasma structures
  - Accelerating shock speed
  - significant modifications to the ion density.



Debris Dispersal

- Debris Ion location
- Isotope separation with present distribution.
- U+ is ahead of the shock



HPC Reguirements

- Currently using:
  - 128 processors on IBM SP3
  - ~63 GB of Ram
  - 64 million zones
  - > 750 million particles
- Output of data is 63 GB per time step dumped (~20 dumps)
- Running time with 128 processors (~250 hours)

Conclusions

- With HPC resources we can now address a critical issue of national defense: Vulnerability of Space Assets to High Altitude Nuclear Explosions.
- New data and new physical understanding is coming from various sources
- With the current & future HPC resources our defense capabilities will be significantly enhanced.